DEPARTMENT OF THE INTERIOR
U.S. FISH AND WILDLIFE SERVICE
REGION 7

FY11 ENVIRONMENTAL CONTAMINANTS PROGRAM
ON-REFUGE INVESTIGATIONS SUB-ACTIVITY

AK - Contaminant Burdens in Storm-Petrels Nesting on St. Lazaria Island, Alaska Maritime NWR
Project ID: 7N25; DEC ID: 200770001.1

(filename: 7N25 AK Petrels 2011 report.doc)

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August 22, 2011
Congressional District 110

ABSTRACT

Sampling of storm-petrel eggs from St. Lazaria Island in 1992 and 1999, suggested that some birds may be accumulating polychlorinated biphenyls (PCBs) at concentrations which exceed avian toxicity thresholds. This southeast Alaskan island is home to a large seabird colony and is part of the Alaska Maritime National Wildlife Refuge. We sampled additional storm-petrel eggs in 2007, evaluating a suite of Persistent Organic Pollutants (POPs) and methylmercury (MeHg) to further define contaminants exposure in these seabirds.

Our results show that storm-petrels on St. Lazaria Island accumulated some organic compounds and methylmercury and transferred these contaminants to their eggs. Egg contaminant residues represent the contaminants present in the bird's breeding territory mesopelagic diet (Hobson et al. 1997).

Flame-retardants, polybrominated diphenyl ethers (PBDEs) have been reported in numerous Arctic species and in other seabirds (She et al., 2004) but were not detected in this study at or above the analytical detection limits (0.00676 to 0.0201 ppm wet weight.).

Metals concentrations in our sampled eggs were not at levels that have been associated with lowered reproduction or other detrimental effects on birds (Eisler 1985a, 1985b, 1987, 1988, 1998; Heinz 1979; Whitworth et al. 1991).

The highest total PCB concentration in the 2007 samples was 5.01 ppm wet weight with a mean of 1.33 ppm wet weight. In general, total PCB concentrations were greater in the 2007 samples than our previous years' samples and were similar to PCB concentrations reported in other Alaska seabird studies (Vander Pol et al. 2004; Vander Pol et al. 2009). Those investigations' PCB levels were generally lower than those reported in other literature.

Methylmercury results from St. Lazaria eggs exceeded avian toxicity thresholds for this contaminant. However, comparison with mercury data from other seabird species' eggs indicates that St. Lazaria storm-petrel eggs have comparable methylmercury concentrations (Braune et al. 2001, Goodale 2008). Our results were also very similar to results from Leach's storm-petrel eggs in two Maine studies (Goodale et al. 2008, 2009).

Based on the small number of samples collected to date, contaminants in storm-petrel eggs from St. Lazaria Island are at relatively low concentrations and do not represent a risk to this population. However**,** extrapolation from such a small sample size is difficult, particularly given the high variability within some of the existing samples. These results represent input of contaminants to the Gulf of Alaska ecosystem through atmospheric and oceanic transport from distant sources and serve as initial baseline for this species in Southeast Alaska. Although concentrations are primarily below toxic thresholds, our egg residues are greater for PCBs and

some organochlorine compounds than data reported in storm-petrel eggs in the past decade from the Queen Charlotte Islands of British Columbia (Elliott and Noble 1993; Elliott et al. 1997) and from Eastern Canada in 1984 (Pearce et al. 1989).

Future sampling of storm-petrels on St. Lazaria is recommended to examine long-term contaminant trends in these species, as pollution sources may change with time and the effects of climate change on contaminant exposure are unknown. Additional sampling of other storm-petrel colonies would be useful to determine if there is a geographical difference in contaminant loads. These data can be used to track contaminant trends in these species within the refuge. Spatial differences in colony contaminant concentrations may suggest different pollution sources pathways of contaminant transport.

KEY WORDS:
St. Lazaria Island, contaminants, storm-petrel eggs, Alaska, seabirds, PCB, methylmercury, PBDE, flame-retardant, DEC ID# 200770001.1, FFS# 7N25, Congressional District 110, Alaska Maritime National Wildlife Refuge

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ACKNOWLEDGEMENTS

We thank USFWS Alaska Maritime National Wildlife Refuge, St. Lazaria Island field crews for storm-petrel egg and carcass collection. Reviewers of this report were P. Johnson. Funding for this study was provided by the U.S. Fish and Wildlife Service, Division of Environmental Quality On-Refuge investigation funds. These samples represent catalog 7040051 and 7040058.

ACRONYMS AND ABBREVIATIONS

This is one of the required sections for the report. Please see Christina's guidance email. Some that I noted are included below. You can provide the rest of the definitions.

ACF	Analytical Control Facility
Al	Aluminum
AMNWR	Alaska Maritime National Wildlife Refuge
As	Arsenic
Ba	Barium
B	Boron
Be	Beryllium
BHC	Benzene hexachloride
Cd	Cadmium
Cu	Copper
CVAA	Cold Vapor Atomic Absorption
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
Fe	Iron
FTSP	Fork-tailed Storm Petrel
GC/EDC	Gas Chromatography/Electron Capture Detector
GC/MS	Gas Chromatography/Mass Spectrometry
GFAA	Graphite Furnace and Cold Vapor Atomic Absorption
GLBA	Glacier Bay National Park and Preserve
HCB	Hexachlorobenzene
Hg	Mercury
HPLC	High Performance Liquid Chromatography
ICP	Inductively coupled plasma
LHSP	Leach's Storm-petrel
LOD	Level of Detection
M	Meters
Mg	Milligrams
MeHg	Methylmercury
Mn	Magnesium
Mo	Molybdenum
n.d.	Non-detect
Ni	Nickel
NWR	National Wildlife Refuge
OCs	Organochlorines
Pb	Lead
PBDEs	Polybromated diphenyl ether congeners
PCBs	Polychlorinated biphenyls

POPs	Persistant Organic Pollutants
QA	Quality Assurance
QAQC	Quality Assurance Quality Control
RPD	Relative Percent Difference
Se	Selenium
SIM	Selection Ion Monitoring Mode
Sr	Strontium
SRM	Standard Reference Material
STAMP	Seabird Tissue Archival and Monitoring Project
USFWS	U.S. Fish and Wildlife Service
V	Vanadium
Zn	Zinc

INTRODUCTION

Background and Justification

Fork-tailed *Oceanodroma furcata* (FTSPa) and Leach's Storm-petrels *O. leucorhoa* (LHSP) are seabirds that travel extensively between breeding areas on coastal islands and more pelagic wintering habitat. FTSP have a more northerly non-breeding distribution while LHSP are found from the Gulf of Alaska to Hawaii. One of the largest breeding colonies for these two species in southeast Alaska is on St. Lazaria Island, part of the Alaska Maritime National Wildlife Refuge (AMNWR; Fig. 1). An estimated 250,000 pairs nest in burrows on the island. Approximately one-third of the island's population is FTSP and two-thirds is LHSP. We estimate that this colony represents about four to five percent of the Eastern Pacific population for FTSP and LHSP, respectively, based on population estimates in Boersma and Silva (2001) and Huntington, et al. (1996).

Contaminants data on storm-petrels are desirable due to vulnerability of these species to oil spills and exposure to other contaminants at-sea. Food sources for both species are similar; primarily surface invertebrates (Palmer 1962), plankton and nekton (Linton 1979), fish (Vermeer and Devito 1988) and other surface matter including flotsam from boat discharges (Boersma and Silva 2001). Storm-petrels also feed on small pieces of fat from marine mammal carcasses (Bent 1922, Cramp and Simmons 1977, Gill 1977), providing a potentially concentrated source of lipophilic contaminants. During FTSP breeding season, most feeding occurs in inshore waters and within 75 km of known colonies (Harrison 1982). Because of their broad geographic range and indiscriminate prey-selection foraging strategy, storm-petrels can be considered indicator species for ocean surface contaminants.

Both species of storm-petrels are long-lived, allowing contaminant bioaccumulation over many years. Several FTSP identified in one study were at least 14 years old (Boersma and Silva 2001), while the oldest banded LHSP was at least 36 years old (Huntington, et al. 1996**).**

Alaska and other arctic and sub-arctic regions are not immune to contamination by chemicals that are able to travel far from their original sources (Fitzgerald et al. 1998, Heiman et al. 2000, AMAP 2002, AMAP 2004). Persistent organic pollutants (POPS) and mercury (Hg) are global pollutants that are transported via atmospheric pathways and ocean currents far from their original sources to remote locations such as St. Lazaria. POPs include a variety of highly toxic and stable organic compounds such as polychlorinated biphenyls (PCBs), dichlorodiphenyltrichloroethane (DDT), dioxins, furans, and chlordanes: POPs include pesticides, industrial chemicals and industrial waste products (EPA 2002).

a Avian species abbreviations follow those of the American Ornithologists Union.

While highly volatile POPs may travel directly to Alaska by long-range atmospheric transport, less volatile POPs reach the region due to the "grasshopper effect", in which they are deposited and revolatilized in a successive northbound pattern (Wania and Mckay 1996). Cold condensation processes enhance mercury deposition in high altitude and high latitude regions (Schindler 1999). Anthropogenic mercury deposition to Alaska appears to be similar in magnitude to that in temperate latitudes (Fitzgerald et al. 2005).

Upon deposition into marine waters, some of these persistent contaminants can be taken up via ingestion and bioaccumulate and biomagnify up food chains. Methymercury (MeHg) is the more toxic and bioavailable form of mercury. Recent research on mercury has found microbial conversion of inorganic mercury to MeHg, formerly thought to occur only in freshwater environments, occurring in Pacific Ocean waters (Sunderland et al. 2009).

Because the oceans play a major role in contaminant distribution, seabirds can be used to monitor contaminants. Seabirds exhibit food chain amplification and eggs are representative of the females body burdens at the time of laying (Verreault et al. 2006). The Seabird Tissue Archival and Monitoring Project (STAMP) data and other investigations have reported elevated concentrations of POPs and mercury in seabird eggs (Christopher et al. 2002; Day et al. 2005; Elliott et al. 1997; Goodale 2008; Vander Pol et al. 2003, 2004, 2009).

Recent seabird contaminant data sets such as STAMP, have focused on murre species (Vander Pol et al. 2004, 2009), also a long-lived seabird of sub-Arctic and Arctic waters. Murres are diving piscivores whereas storm-petrels feed primarily on macrozooplankton at the ocean's surface. Therefore direct comparisons cannot be made between these seabird species. However these murre egg contaminants data are still of interest and complement studies such as this one, as St. Lazaria is one of the sampling locations for the STAMP program.

Other Southeast Alaska studies indicated the region is being impacted by mercury and POPs. POP concentrations in common murre eggs from Gulf of Alaska islands were significantly higher than Bering Sea colonies (Christopher et al. 2002, Day et al. 2004). St. Lazaria murre eggs had higher concentrations of the sum of 46 PCB congeners than eggs from any other Alaskan colony (Hood et al. 2006). Mercury pollution may be more of a concern in Southeast Alaska compared to other regions of Alaska (Christopher et al. 2002, Day et al. 2004). Dated sediment cores from lakes in Glacier Bay National Park and Preserve (GLBA) indicated modern mercury accumulation rates in sediments are approximately double pre-industrial accumulation rates (Engstrom and Swain 1997). Additionally, mercury deposition in GLBA did not show recent declines (since the1960s) observed at sites in the continental US where regional mercury emissions have been reduced (Hood et al. 2006). These results suggest that Southeast Alaska is being affected by mercury emissions from remote sources (e.g. in Asia), that are steadily increasing their output (Pacyna and Pacyna 2002). Limited studies to date strongly suggest that the threats posed by mercury and POPs to ecosystems in southeast Alaska are significant and deserve further evaluation and monitoring (Hood et al. 2006).

We previously assessed contaminants in storm-petrels from St. Lazaria (Rudis 1996, Rudis and Slater 2004). An initial investigation focused on soil contaminants on St. Lazaria Island (Rudis 1996); an addled storm-petrel egg (species unknown) was also opportunistically collected and analyzed for metals and a variety of organic compounds. In September 2000, four addled storm-petrel eggs and one dead chick were collected from nest burrows on St. Lazaria Island (Rudis and Slater 2004). The 2000 samples were analyzed for lipid content, MeHg, total PCBs, DDT and metabolites, chlordane-related compounds, hexachlorobenzene (HCB), dieldrin, mirex, and other organochlorines.

Results from this earlier investigation suggested that some storm-petrels on St. Lazaria Island may be accumulating organochlorine pesticides and PCBs. One egg had an extremely high total PCB concentration of 16.0 ppm wet weight, which exceeded avian toxicity thresholds. In addition, murre eggs collected from St. Lazaria for the STAMP program had significantly higher POPs concentrations than those collected from Bering Sea colonies (Vander Pol, et al. 2004). These data prompted us to collect and analyze additional storm-petrel eggs to determine if any contaminants were at concentrations that could present a risk to this population.

Scientific Objectives

1. Measure contaminant concentrations in storm-petrel eggs from St. Lazaria Island, Alaska Maritime NWR.
2. Compare St. Lazaria storm-petrel egg contaminants data among years and with contaminants data from other locations.
3. Determine if contaminants in storm-petrel eggs are at concentrations of concern when compared to toxicity benchmarks and other literature values.
4. Provide novel contaminants data on bird species that have little or no information available in the published literature.

STUDY AREA

St. Lazaria is a 26 hectare island located at the mouth of Sitka Sound, approximately fifteen miles southwest of Sitka, Alaska, on the outer coast of the southeast Alaska Archipelago (Fig. 1). The island is part of the Alaska Maritime National Wildlife Refuge. It was originally designated as a "refuge for seabirds" in 1909, and received official wilderness designation from Congress in 1970.

The island has broken terrain due to its volcanic origins with its highest point at 55 meters (m) above sea level. There are two small summits on the island with a low, bedrock saddle connecting the two. Mostly loamy soils elsewhere on the island provide nesting habitat for the island's burrowing seabirds. Other geographic features are cliffs up to about 40 m and sea-level caves. The summits and tops of rugged cliffs at either end of the island are vegetated with mature Sitka spruce (*Picea sitchensis*), lush grasses, and dense brush thickets of salmonberry (*Rubus spectabilis*), wild currant (*Ribes* sp.), elderberry (*Sambucus racemosa*), and fern (*Athyrium filix-femina*). Petrel burrows riddle the ground across the island with highest densities in areas dominated by ferns and ryegrass (*Leymus* sp.).

Over 560,000 breeding seabirds, primarily fork-tailed and Leach's storm-petrels (*Oceanodroma furcata, O. leucorhoa*) occur on the island. Other species include common murre (*Uria aalge*), thick-billed murre (*U. lomvia*), tufted puffin (*Fratercula cirrhata*), ancient murrelet (*Synthliboramphus antiquus*), rhinoceros auklet (*Cerorhinca monocerata*), and pigeon guillemot (*Cepphus columba*). It is the second largest seabird colony in southeast Alaska. In addition, eight passerine and two raptor species nest on the island.

St. Lazaria was part of the military complex in Southeast Alaska during World War II, and remnants of old infrastructure still remain. It primarily served as an aircraft warning station with radar equipment and limited housing. Because of its spectacular seabird colonies and dramatic appearance, it is a popular area for wildlife viewing by organized commercial tour boat operations from Sitka. Offshore sport fishing is also very popular. St. Lazaria is passed by cruise ships that enter Sitka Sound, and other commercial vessels travel through offshore waters.

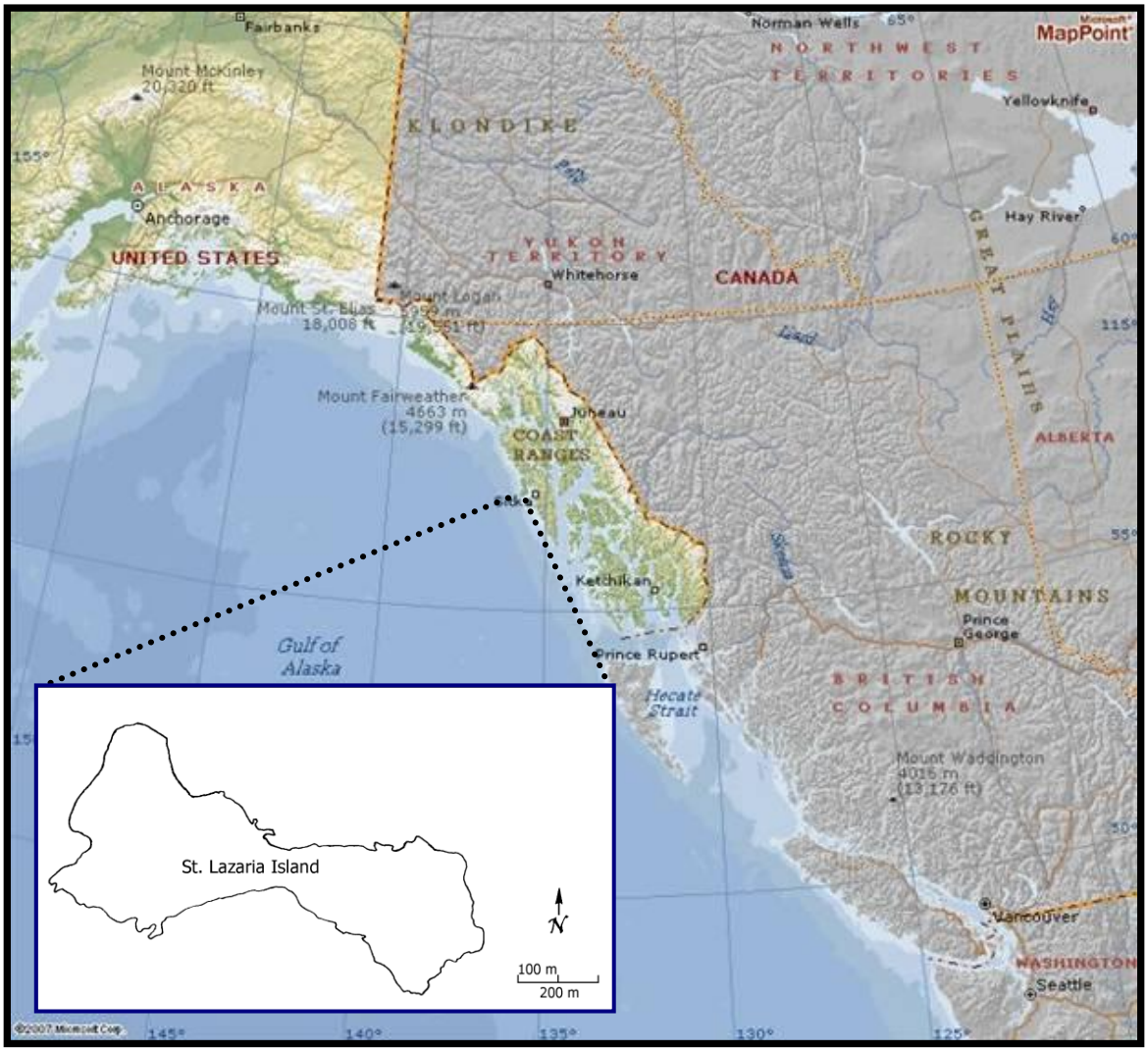

Figure 1. Location of St. Lazaria Island in Southeast Alaska (western Sitka Sound, 56°59'N 135°42'W).

METHODS AND MATERIALS

Sample Collection

For this investigation, addled egg (n = 12) and chick carcass (n = 2) samples were collected from St. Lazaria in 2007

Eggs and dead chicks were removed from burrows, wrapped in aluminum foil, put in secondary containers, kept cold and shipped to the U.S. Fish and Wildlife Service Field Office in Juneau,

Alaska. Samples were removed from their containers and foil wrap and weighed. Eggs were lightly rinsed with distilled water before eggshells were cut with surgical scalpels and contents removed. Egg contents and carcasses were transferred to chemically clean jars, reweighed and frozen. Samples from 2007 were shipped frozen to TDI Brooks International (TDI) Inc. at College Station, Texas for analyses. One egg sample was accidentally dropped at that lab and was not included in some of the analyses.

Organic analyses of sample tissues collected in 2000 (n = 4) were done at the former U.S. Fish and Wildlife Service Patuxent Analytical Control Facility. Samples from 2007 (n = 14, egg and carcass data combined) were analyzed for organic compounds at TDI. Tissue samples from all years were analyzed for percent lipid content; and for contaminants listed above. All organic and MeHg contaminant concentrations are reported in ppm wet weight. Soil metal data are presented in ppm dry weight.

Standard laboratory analytical procedures included procedural blanks, duplicates, standard reference materials, and spike recoveries, where a known mass of target analyte was added to a blank sample or subsample. This technique is used to determine recovery efficiency of for other quality control purposes.

Laboratory Methods

Samples were analyzed for a suite of organic contaminants and MeHg analyses. To further define contaminants in these seabirds, tested organic compounds included:

- a number of Persistent Organic Pollutants (POPs),
- polychlorinated biphenyls (PCBs),
- a variety of organochlorine pesticides (OCs; e.g., dichlorodiphenyltrichloroethane (DDT) and
- metabolites, chlordane-related compounds, dieldrin, mirex, and hexachlorobenzene (HCB), and
- flame retardants which are a suite of polybromated diphenyl ether congeners (PBDEs),

We included PBDE analyses as there are no PBDE data for storm-petrels, and few data for Alaskan birds in general.

Metals Extraction and Determination

Metal analyses were conducted at Research Triangle Institute, in Research Triangle Park, NC. Samples were first homogenized and freeze-dried material was ground to 100 mesh with a mill. Digestion for Graphite Furnace and Cold Vapor Atomic Absorption (GFAA) Measurement used nitric acid. Inductively coupled plasma (ICP) measurements were made using a Leeman Labs SpecI sequential or an ES2000 simultaneous spectrometer. Analytes included aluminum, arsenic, barium, boron, beryllium, cadmium, copper, iron, manganese, magnesium,

molybdenum, nickel, lead, strontium, vanadium, and zinc. GFAA measurements for selenium were made using an-Elmer Zeeman 3030 or 4100ZL atomic absorption spectrometer. Mercury measurements were made by Cold Vapor Atomic Absorption (CVAA). Mercury measurements were conducted with a Leeman PS200 Hg analyzer. SnC_{14} was the reducing agent. Methylmercury extraction included treatment with HCl and toluene.

Tissue Extraction Method for Organochlorines (OCs)

Frozen tissue samples were homogenized and a 1 gram (g) aliquot was removed and dried in an oven at 105°C to a constant weight for percent moisture. Remaining samples were stored frozen (- 20°C) until analysis. Analytical methods used by TDI are summarized below:

Samples are extracted using a Dionex ASE200 Accelerated Solvent Extractor (ASE). Dissolved extracted organics are collected and concentrated to approximately 10 milliliter (mL). For lipid weight, a 100 mL aliquot is removed and weighed using a microbalance. Interfering non-contaminant organic material (primarily lipids) were removed prior to instrument analyses.

Extract is processed through silica gel/alumina chromatography columns and High Performance Liquid Chromatography (HPLC). Remaining 2.9 mL of sample extracted are loaded on top of 300 mm x 19 mm glass liquid chromatography columns packed with 10 g of deactivated alumina and 20 g of deactivated silica gel. Columns are loaded in 100 percent dichloromethane. Dichloromethane is replaced by adding 40 mL of pentane. Extract is carefully added to the top of the chromatography columns. Eluent is evaporated to 2 mL. Extracts are subsequently processed by HPLC to further remove lipid interferences. Approximately 40 mL is collected and concentrated. The concentrated extract is then analyzed by Gas Chromatography/Electron Capture Detector (GC/ECD) for selected organochlorines (OCs).

Additional column chromatography is required to separate PCBs from toxaphene/pesticides when toxaphene analysis is required and to separate planar PCBs. For toxaphene analyses, an aliquot of the extract prior to HPLC clean up is processed through a 3 percent deactivated silica gel column. Sample extract is flushed with 100 mL of pentane. If the fraction contains PCBs and DDTs, the column is then flushed with 120 mL of 50:50 pentane/dichloromethane. The resulting fraction can contain toxaphene and chlorinated pesticides. Both fractions are reduced to 1 mL using a water bath at 55-60°C. Extracts are then ready for instrument analysis. For planar PCB analyses, the PCB/DDT fraction prepared by 3percent silica gel column is further processed by column chromatography packed with 2 g of 1:19 (5 percent by weight) mixture of activated carbon/Celite. A series of flushing is followed by the addition of 40 mL of toluene. This toluene fraction contains the planar PCBs and is concentrated to 1 mL in a Zymark TurboVap II device. The sample is ready for instrument analysis.

Chlorinated Hydrocarbon Determination

Chlorinated hydrocarbons are determined in samples by GC/ECD. Samples are extracted as previously described and analyzed on a HewlettPackard (HP) model 5890 GC equipped with an

ECD. Between 1 to 5 mL of sample is injected using an HP model 7673A autosampler set up with dual columns. The inlet system is splitless and the carrier gas is helium at a flow rate of 1 mL/min. For planar PCBs the instrument is operated in the splitless mode with helium as the carrier gas. Levels of aroclors and toxaphene are determined using retention index solutions of both complex mixtures. Arochlors are determined in a similar method to that described in EPA 1997.

Confirmation of Analytes

The presence of pesticides and PCBs is confirmed by Gas Chromatography/Mass Spectrometry (GC/MS) in either full scan or selection ion monitoring mode (SIM). Samples are extracted as previously described. Samples were initially screened by GC/ECD and GC/MS to confirm the presence of specific analytes in a sample. Analytes detected at 10 times the SIM limit of detection may be confirmed by SIM GC/MS. Samples are analyzed on a Hewlett Packard 5890GC/ 5972MS. The analytical column was an Agilent Technologies HP5MS (60 m x 0.25 mm ID and with a 0.25 mm film thickness). Carrier gas was helium with a flow rate of 1mL/min. Chromatographic peaks must be at least 3 times the background noise and must be within once scan of each other and match the retention time of the standard run under the same conditions to be "confirmed".

Polybrominated Diphenyl Ether (PBDE) Determination

PBDE determination was by Negative Chemical Ionization –SIM GC/MS. PBDEs were analyzed in sample extracts by a Thermo Trace GC and DSQ-II MS operated in SIM using a capillary column. The GC was operated in splitless mode using a PTV injection port and the capillary column was an Agilent Technologies DB-XLB. Carrier gas was helium with methane used as the reactant gas.

Moisture content of tissue samples for mercury analysis

Moisture content is determined by weight loss upon freeze-drying, and is expressed as weight percent of the original wet sample. The sample or a representative aliquot was frozen and then dried under vacuum until a constant weight was attained. Samples were prepared and dried using plastic materials, whenever possible, in order to minimize potential contamination artifacts that might impact subsequent trace element analysis.

Determination of methylmercury in tissue

Methylmercury determination measured the sum of all organo-mercury species extracted into the solvent. This method determination was essentially equivalent to the GC method for analyzing MeHg in fish muscle tissue (where almost all of the organomercury is present as MeHg). Samples were analyzed either wet or after freeze-drying. Homogenized aliquots were extracted in to an organic solvent. The organic phase was digested using nitric and sulfuric acids and potassium permanganate to convert all mercury species to ionic mercury and to remove traces of organic solvent that would otherwise impact the measurement. Analysis was based upon the cold vapor atomic absorption method, although cold vapor atomic fluorescence can be used

when lower detection limits are required.

Quality Assurance/Quality Control

Methods for egg and carcass collection followed standard protocols as described by U. S. Fish and Wildlife Service (1996) with minor revisions. Laboratory quality assurance and quality control (QAQC) procedures followed USFWS Analytical Control Facility (ACF) contractual standards. With each sample batch there was at least one duplicate, one sample spike, one analytical blank, and one appropriate Standard Reference Material (SRM) were assayed. The Quality Assurance (QA) program for residue data was conducted at ACF where results of duplicates, spike recoveries, and procedural blanks were reviewed to determine laboratory data acceptability. Acceptable accuracy for percent recovery of analytes in spiked samples was ≥ 80 percent. Acceptable relative percent difference (RPD) of duplicate samples was within 20 percent.

The ACF QA officer reviewed these data to ensure that they met U.S. Fish and Wildlife Service standards before they were sent to the investigator. Laboratory QA data are included in Appendix A.

RESULTS

Overview: Contaminant Concentrations and Detection Limits

Among all year samples, organic contaminant concentrations in storm-petrel egg and carcass samples varied from below detection limits to a concentration of 16.0 ppm wet weight total PCBs, in one of the year 2000, egg samples. All organic contaminant and MeHg concentrations are reported in ppm wet weight. MeHg concentrations were reported for both year 2000 and 2007 samples. Metal concentrations (reported as both dry weight and wet weight), were only determined in the year 2000 storm-petrel samples because they were low enough and not of concern.

Organochlorine contaminants that were below detection limits in all year 2007 samples included - aldrin; 1, 2, 3, 4 – tetrachlorobenzene; 1, 2, 3, 4, 5-tetrachlorobenzene; heptachlor; pentachloro-anisole; delta BHC; gamma chlordane; endosulfan I; and toxaphene.

Endosulfan II and endosulfan sulphate were reported at trace levels in five samples. Beta BHC was reported at a trace level in one sample.

All year 2007 samples had PBDEs reported at below limits of detection. Analyses were done on 37 PBDE congeners.

Percent lipid ranged from 11.8 to 24.3, with a geometric mean of 15.16 percent. Egg content weights (shells removed) are included in Appendix A. Mean egg weight was 6.72 g.

PCBs

A wide concentration range was observed for total PCBs (nondetect [n.d]. - 16.0 ppm wet weight) from the earlier samples collected in 1992 and 2000 (Table 1). The 2007 samples had total PCB concentrations that ranged from 0.294 to 5.01 ppm wet weight, with a geometric mean ($\bar{x}$) of 1.33 ppm wet weight. (Table 2). Analyses on 2007 samples were performed for PCB congeners 1242, 1248, 1254, and 1260. All samples were below detection limits for PCB-1242 and 1248. PCB residues detected were from congeners 1254 and 1260.

Samples with higher PCB concentrations did not correspond with the samples that had the highest percent lipid values.

Organochlorine Pesticides

A wide concentration range was observed for, p, p'- DDD (n.d. - 0.871 ppm wet weight), and p, p' - DDE (1.2 - 9.61 ppm wet weight) in preliminary year samples. Concentrations of p,p'-DDT were 0.175 to 0.444 ppm wet weight(Table1). Samples from 2007 had total DDT concentrations from 0.202 to 2.45 ppm wet weight (Table 2). All six DDT metabolites (o,p'-DDD; o,p'-DDE; o,p-DDT; p,p'-DDD; p,p'-DDE; p,p'-DDT) were detected in all but one sample. Metabolite p, p'-DDE was responsible for 73 to 88 percent of total DDT values in these samples ($\bar{x}$ = 79.1).

DDMU is a compound formed from DDE by microbial action, concentrations of this organochlorine ranged from 0.000941 to 0.00462 ppm wet weight

Lindane or BHC (benzene hexachloride), was reported in 12 of the 2007 samples. Total BHC consists of all the mixed isomer degradants from the organochlorine insecticide lindane. Total BHC concentrations ranged from below detection limit in one sample, to 0.154 ppm wet weight ($\bar{x}$ = 0.030). In 2000 year samples, alpha-, beta-, and gamma-BHC were not found at detection limits.

Chlorpyrifos, an organophosphate insecticide, was below detection limits in seven of the 2007 samples. Concentrations in the other six samples ranged from 0.0079 up to 0.0267 ppm wet weight. As noted in the QA/QC review, chloropyrifos data could be biased low. Chloropyrifos was not tested for in the 2000 year samples.

Table 1. Sample weight, percent lipid, organic analytes (ppm, wet weight) and Detection Limits (LOD), from storm-petrel eggs, St. Lazaria Island, Alaska, 2000.

Sample ID	sample wt. (g)	% lipid	HCB	LOD	PCB - Total	LOD	cis-nonachlor	LOD	dieldrin	LOD	heptachlor epoxide	LOD	mirex	LOD	o,p'-DDD	LOD	o,p'-DDE	LOD	oxychlordane	LOD	p,p'-DDD	LOD	p,p'-DDE	LOD	p,p'-DDT	LOD	trans-nonachlor	LOD
SPE1705	15.4	32.6	0.163	0.010	<.050	0.050	0.370	0.010	<0.01	0.010	<0.010	0.010	0.148	0.010	<0.010	0.010	0.207	0.010	<0.0100	0.010	0.167	0.010	1.200	0.010	0.217	0.010	0.239	0.010
SPE203	7.8	21.4	0.125	0.010	<.050	0.050	0.667	0.010	<0.01	0.010	<0.010	0.010	0.250	0.010	<0.010	0.010	0.306	0.010	0.458	0.010	<0.0100	0.010	5.280	0.010	0.444	0.010	0.465	0.010
SPEF701	8.0	24.1	0.114	0.010	<.050	0.050	0.324	0.010	<0.01	0.010	<0.010	0.010	0.107	0.010	<0.010	0.010	0.141	0.010	<0.0100	0.010	0.138	0.010	2.310	0.010	0.183	0.010	0.310	0.010
SPEL1804	8.0	13.2	0.140	0.010	<.050	0.050	0.211	0.010	<0.01	0.010	<0.010	0.010	0.123	0.010	<0.010	0.010	0.172	0.010	<0.0100	0.010	<0.0100	0.010	1.330	0.010	0.175	0.010	0.211	0.010
SPEL202	8.0	26.6	0.176	0.010	16.0	0.050	0.953	0.010	0.094	0.010	0.094	0.010	0.447	0.010	0.176	0.010	0.447	0.010	0.635	0.010	0.871	0.010	9.610	0.010	0.200	0.010	0.906	0.010

Sample ID[1] SPE- unidentified storm-petrel egg, SPEF - fork-tailed storm-petrel, SPEL - Leach's storm-petrel

Table 2. Sample weight, percent lipid, organic analyses (ppm, wet weight) and Limits of Detection (LOD) for Storm-petrels, St. Lazaria Island, Alaska, 2007.

Sample ID[1]	egg/carcass wt (g)	% lipid	PCBs - Total	LOD	DDTs - Total	% p'p-DDE	LOD	p-p DDE	LOD	HCB	LOD	BHC- Total	LOD	dieldrin	LOD
FSP09E	7.2	19.4	2.89	0.0114	1.23	81	0.00198	0.995	0.00028	0.0857	0.00035	0.0316	0.00132	0.0145	0.000556
FSP11E	7.1	11.8	2.47	0.0114	0.979	82	0.00198	0.799	0.00028	0.0535	0.00035	0.0367	0.00132	0.0158	0.000556
FSP12E	8.5	18.7	3.27	0.0114	1.94	82	0.00198	1.6	0.00028	0.138	0.00035	0.154	0.00132	0.0832	0.000556
FSP13E	4.6	13.8	1.19	0.0114	0.82	85	0.00198	0.695	0.00028	0.0718	0.00035	0.096	0.00132	0.0435	0.000556
LSP02E	7.1	13.5	0.546	0.0116	0.264	80	0.00202	0.21	0.00029	0.0194	0.00036	0.0105	0.00135	0.00532	0.000567
USP01E	4.4	13.2	5.01	0.0114	2.45	88	0.00198	2.15	0.00028	0.074	0.00035	0.0682	0.00132	0.0497	0.000556
USP03E	6	16.1	0.603	0.0117	0.267	74	0.00204	0.198	0.00029	0.0242	0.00036	0.0124	0.00136	0.00525	0.00057
USP04E	5.9	18.6	0.682	0.0114	0.319	73	0.002	0.232	0.00028	0.0243	0.00035	0.0165	0.00133	0.00528	0.000559
USP06E	8.1	13.8	1.83	0.0115	0.79	76	0.002	0.613	0.00029	0.0337	0.00036	0.0235	0.00134	0.0153	0.000562
USP08E	6.8	12.6	1.29	0.0116	0.501	77	0.00202	0.385	0.00029	0.0427	0.00036	0.0143	0.00135	0.00495	0.000567
USP10E	7.4	14	1.49	0.0114	0.807	78	0.00198	0.633	0.00028	0.0491	0.00035	0.0239	0.00132	0.0109	0.000556
FSP07C	8.3	12	1.27	0.0117	0.459	80	0.00204	0.367	0.00029	0.0384	0.00036	0.0291	0.00136	0.0128	0.00057
LSP14C	17.3	24.3	0.294	0.0116	0.202	74	0.00202	0.15	0.00029	0.0151	0.00036	0.03025	0.00135	0.00422	0.000567
Geomean	6.52 (eggs only)	15.16	1.33		0.642	0.642		0.508		0.043		0.03025		0.01289	

Sample ID[1]

FSP- Fork-tailed storm-petrel, LSP- Leach's storm-petrel, USP- unknown species storm-petrel, E- egg, C- carcass

Table 2. Continued

Sample ID[1]	endrin	LOD	mirex	LOD	lindane	LOD	oxychlordane	LOD	heptachlor epoxide	LOD	penta-chlorobenzene	LOD
FSP09E	0.00753	0.00053	0.0809	0.00031	<0.000371	0.00037	0.109	0.0004	0.0119	0.00036	0.00263	0.00259
FSP11E	0.00529	0.00053	0.0889	0.00031	<0.000371	0.00037	0.12	0.0004	0.00978	0.00036	0.00253	0.00259
FSP12E	0.00474	0.00053	0.0787	0.00031	<0.000371	0.00037	0.161	0.0004	0.0341	0.00036	0.00294	0.00259
FSP13E	0.00329	0.00053	0.0312	0.00031	0.00402	0.00037	0.0863	0.0004	0.0191	0.00036	0.00225	0.00259
LSP02E	0.00251	0.00054	0.0102	0.00032	<0.000378	0.00038	0.0139	0.0004	0.00295	0.00036	0.0023	0.00264
USP01E	<0.000527	0.00053	0.127	0.00031	<0.000371	0.00037	0.2	0.0004	0.0277	0.00036	0.00277	0.00259
USP03E	0.00428	0.00054	0.0171	0.00032	0.00434	0.00038	0.015	0.0004	0.00346	0.00037	0.00265	0.00265
USP04E	0.00483	0.00053	0.0199	0.00031	0.00463	0.00037	0.0166	0.0004	0.00405	0.00036	0.00275	0.0026
USP06E	0.00497	0.00053	0.0615	0.00032	0.000432	0.00037	0.0748	0.0004	0.00776	0.00036	0.00212	0.00261
USP08E	0.00419	0.00054	0.0363	0.00032	<0.000378	<0.000371	0.0788	0.0004	0.0056	0.00036	0.00173	0.00264
USP10E	0.0049	0.00053	0.0493	0.00031	<0.000371	0.00037	0.0895	0.0004	0.00782	0.00036	0.00208	0.00259
FSP07C	0.00243	0.00054	0.0358	0.00032	0.000566	0.00038	0.0887	0.0004	0.0058	0.00037	0.00224	0.00265
LSP14C	0.00211	0.00054	0.00306	0.00032	<0.000378	0.00038	0.0063	0.0004	0.00216	0.00036	0.00236	0.00264
Geomean (eggs only)	0.004002		0.03438				0.0544		0.00776		0.002389	

Sample ID[1]

FSP- Fork-tailed storm-petrel, LSP- Leach's storm-petrel, USP- unknown species storm-petrel, E- egg, C- carcass

Table 2. Continued

Sample ID[1]	chlorpyrifos	LOD	trans-nonachlor	LOD
FSP09E	0.0109	0.000317	0.12	0.000361
FSP11E	0.01222	0.000317	0.0903	0.000361
FSP12E	0.0267	0.000317	0.202	0.000361
FSP13E	0.00934	0.000317	0.0843	0.000361
LSP02E	<0.000323	0.000323	0.0447	0.000368
USP01E	<0.000317	0.000317	0.183	0.000361
USP03E	<0.000325	0.000325	0.0517	0.00037
USP04E	<0.000319	0.000319	0.0587	0.000363
USP06E	<0.00032	0.00032	0.0666	0.000365
USP08E	0.00847	0.000323	0.0801	0.000368
USP10E	0.0079	0.000317	0.0806	0.000361
FSP07C	<0.000325	0.000325	0.0682	0.00037
LSP14C	<0.000323	0.000323	0.0258	0.000368
Geomean (eggs only)			0.0772	

Sample ID[1]

FSP- Fork-tailed storm-petrel, LSP- Leach's storm-pet

Cis-nonachlor, oxychlordane, trans-nonachlor and gamma-chlordane are all chlordane-related compounds. Concentration range for cis-nonachlor in 2007 samples was 0.00262 – 0.0139 ppm wet weight; oxychlordane, 0.006 – 0.161 ppm wet weight, and trans-nonachlor 0.0258 – 0.202 ppm wet weight All samples were below detection limits for gamma-chlordane.

Different chlordane compounds were analyzed in the 2000 year samples. Concentrations were below detection limits for alpha- , and gamma-chlordane. Cis-chlordane concentrations were 0.21- 0.953 ppm wet wt; oxychlordane results were 0.268 – 0.635 ppm wet weight.

Dieldrin, a breakdown product of aldrin was detected in all 2007 samples and in two of the earlier years' samples. Concentrations in 2007 samples ranged from 0.00422 to 0.0832 ppm wet weight, in a 1992 sample at 0.04 ppm wet weight, and a 2000 sample at 0.094 ppm wet weight

Endosulfan I is a current-use pesticide, but was not found at detection limits in any 2007 samples. Endosulfan II was reported in two 2007 samples at 0.0174 and 0.0309 ppm wet weight. Endosulfan sulfate is a breakdown product of endosulfan. It was only detected in two 2007 samples, at 0.0111 and 0.0104 ppm wet weight

Endrin was not detected in the 2000 year samples. It was detected in all but one 2007 year samples. Concentrations ranged from below detection limit to 0.00753 ppm wet weight ($\bar{x}$ = 0.0040).

Our hexachlorobenzene (HCB) results were similar among 2000 year samples (range: 0.114 - 0.176 ppm wet weight). Samples from 2007 had a lower range of HCB concentrations, 0.0151 to 0.138 ppm wet weight ($\bar{x}$ = 0.0427).

Mirex concentrations in 2000 year samples ranged from 0.107 to 0.447 ppm wet weight Concentrations were lower in 2007 year samples, with a range of 0.00306 to 0.127 ppm wet weight ($\bar{x}$ = 0.0344).

Pentachlorobenzene is used as a fungicide and fire retardant. It was detected in 2007 year samples in trace concentrations, ranging from 0.00173 to 0.00294 ppm wet weight

1,2,4,5 – Tetrachlorobenzene concentrations were very low and ranged from below detection limit to 0.000845 ppm wet weight in 2007 year samples.

Heptachlor epoxide, a breakdown product of heptachlor, was detected in all 2007 samples and one 2000 year sample. Concentration range for 2007 samples was 0.00216 to 0.0782 ppm wet weight. The 2000 year sample was reported at 0.0941 ppm wet weight

Methylmercury

Methylmercury in the 1992 egg sample was 0.327 ppm wet weight Results for the five samples collected in year 2000 ranged from 0.216 to 1.06 pm wet weight ($\bar{x}$ = 0.463), (Table 3). Year 2007 egg samples had a range of 0.438 to 1.08 ppm wet wt ($\bar{x}$ = 0.683), (Table 4). The two storm-petrel carcasses' methylmercury values were 0.209 and 0.683 ppm wet weight.

Table 3. Methylmercury (ppm, wet weight) and Detection Limits (DL) in Storm-petrel eggs, St. Lazaria Island, Alaska, 2000.

Sample ID	Wet wt.	DL
E1705	0.428	0.0037
E203	0.216	0.0364
F701	1.06	0.0653
L1804	0.422	0.0258
L202	0.514	0.0425
Geomean	0.4629092	

Sample ID[1] E- unidentified storm-petrel egg, F - fork-tailed storm-petrel, L - Leach's storm-petrel

Table 4 . Methlymercury (ppm, wet weight) and Detection Limits (DL) in Storm-petrels from St. Lazaria Island, Alaska, 2007.

Sample ID[1]	Egg (E) Carcass (C)	ppm Wet Wt	DL
FSP09E	E	0.764	0.00483
FSP11E	E	0.588	0.00643
FSP12E	E	0.956	0.00482
FSP13E	E	0.445	0.00536
LSP02E	E	0.593	0.00596
USP01E	E	0.954	0.0112
USP03E	E	0.63	0.0059
USP04E	E	0.438	0.00413
USP05E	E	0.636	0.0071
USP06E	E	0.793	0.0166
USP08E	E	1.08	0.0171
USP10E	E	0.637	0.00408
GeoMean E only		0.683256	
FSP07C	C	0.268	0.00385
LSP14C	C	0.163	0.00507
Geo Mean E+C		0.209007	

Sample ID[1] FSP - Fork-tailed storm-petrel, LSP - Leach's storm-petrel, USP - unidentified species of storm-petrel, E- egg, C- carcass

Other Metals

Metal concentrations in year 2000 egg samples included analyses for aluminum (Al), arsenic (As), barium (Ba), boron (B), beryllium (Be), cadmium (Cd), copper (Cu), iron (Fe), manganese (Mn), magnesium (Mg), mercury (Hg), molybdenum (Mo), nickel (Ni), lead (Pb), selenium (Se), strontium (Sr), vanadium (V), and zinc (Zn) (Table 5). Metals that were not found at detection limits were As, Be, Cr, Ni, and V. Out of the five egg samples, Cd and Ba were reported at or above detection limits in three samples, and Pb and Se in two samples.

All organic and inorganic analytical results, including dry and wet weights and laboratory QA data are available from the first author.

Table 5. Metal concentrations (ppm, dry weight) and Detection Limits (LOD) in Storm-petrel eggs, St. Lazaria Island, AK, 2000.

Sample ID[1]	Aluminum	LOD	Boron	LOD	Barium	LOD	Cadmium	LOD	Copper	LOD	Iron	LOD	Mercury	LOD	Magnesium	LOD	Manganese	LOD	Lead	LOD	Selenium	LOD	Strontium	LOD	Zinc	LOD
E1705	0.976	0.321	0.541	0.16	<0.321	0.321	<0.0161	0.0161	1.37	0.0321	54.2	1.61	0.567	0.0161	541	1.61	0.313	0.096	<0.0161	0.0161	<0.160	0.16	19.9	0.0321	13.6	0.321
E203	1.44	0.336	0.681	0.168	3.67	0.336	<0.0168	0.0168	2.25	0.0336	84.1	1.68	0.91	0.0168	534	1.68	0.434	0.101	<0.0168	0.0168	0.352	0.168	53.4	0.0336	25.3	0.336
F701	1.96	0.625	0.772	0.313	<0.625	0.625	0.0355	0.0313	2.95	0.0625	81	3.13	0.886	0.0313	973	3.13	0.858	0.188	0.0374	0.0313	0.333	0.313	58.3	0.0625	25.1	0.625
L1804	1.41	0.246	0.531	0.123	0.272	0.246	0.017	0.0123	1.22	0.0246	51.3	1.23	0.384	0.0123	521	1.23	0.39	0.737	<0.0123	0.0123	<0.123	0.123	20.8	0.0246	13.6	0.246
L202	1.97	0.391	1.03	0.196	3.94	0.391	0.0196	0.0196	1.46	0.0391	63.5	1.96	0.784	0.0196	559	1.96	0.389	0.117	0.0294	0.0196	<0.196	0.196	132	0.0391	19.1	0.391

Sample ID[1] E- unidentified storm-petrel egg, F - fork-tailed storm-petrel, L - Leach's storm-petrel

Quality Assurance/Quality Control - 2000 Samples

Tissue Samples - Organic Compounds

Egg samples for 2000 did not have procedural blanks above the detection limits for any samples. Duplicate analyses of all analytes had a RPD of ≤ 20 percent and were all acceptable. Spiked sample recoveries were ≥ 80 percent of the expected value and were acceptable. All spikes were within normal limits. There were no Standard Reference Material (SRM) tests conducted for this sample set.

Metals and Methylmercury

Laboratory duplicate analyses for barium and MeHg in 2000 samples analyses was > 20 percent RPD. All other duplicate analyses had RPDs that were ≤□ 20 percent. Laboratory comments noted that the variability of the duplicate for MeHg was higher than normally seen, but should have no effect on data interpretation. The spike recovery for cadmium in the SRM (lobster hepatopancreas) was high and low for nickel. The variability of the MeHg duplicate was 38 percent RPD. Although the laboratory report stated that this result should have no effect on the data interpretation, this variability is higher than normally seen.

Most percent recoveries for metals spike samples were within the normal limits of ACF acceptable ranges and are considered qualitative. Spike to background ratios were below 1.0 for mercury and strontium, indicating these data cannot be used as a measure of matrix effects. These data can only be considered qualitative; there is too much variability in the data for quantitative analyses.

Data review incorporates all components of the QA program, accordingly, RPD, LOD and spike samples must be considered to determine data accuracy. Incorporating these QA components for this data set review allows quantitative analyses for all metals except those that did not meet QAQC requirements as previously noted. All other metals data can be used on a qualitative basis.

Quality Assurance/Quality Control - 2007 Samples

Tissue Samples - Organic Compounds

Egg samples for 2007 did not have procedural blanks above the detection limits for any samples. Duplicate analyses analytes had a relative percent difference (RPD) of ≤20 percent except for 1, 2, 4, 5- tetrachlorobenzene and alpha chlordane. These two compounds did not meet the ≤ 20 percent criteria. All other analytes were acceptable. Spiked sample recoveries that were ≥ 80 percent of the expected value were acceptable. All spikes except, 1, 2, 4, 5- tetrachlorobenzene; chlorpyrifos; endosulfan II; and endosulfan sulfate were within normal limits. In particular the laboratory report notes that chlorpyrifos results may be biased low. Data can only be considered qualitative for these four compounds; there is too much data variability for quantitative analyses. There were no SRM tests conducted for this sample set.

DISCUSSION

Our results show that adult storm-petrels on St. Lazaria Island are accumulating some organic compounds and methylmercury and transferring these contaminants to their eggs. Egg contaminant residues represent the pollutants present in the bird's breeding territory diet (Hobson et al. 1997). Storm-petrels are mesopelagic feeders, reflecting contaminant concentrations of that ecosystem. As nocturnal foragers, storm-petrels feed on invertebrates and mesopelagic fish which are found at or near the ocean surface. Some prey species migrate and feed vertically in the water column, so contaminant acquisition is not restricted to surface waters. Contaminant loads in these fish represent anthropogenic input into the marine environment, through atmospheric and oceanic transport of industrial discharges from coal combustion and industrial waste disposal.

Flame-retardants, polybrominated diphenyl ethers (PBDEs), have been reported in numerous Arctic species and in other seabirds (She et al. 2004). In this study, none of the PBDEs were detected at or above the analytical detection limits which ranged from 0.00676 to 0.0201 ppm wet weight. By comparison, in Maine, one LHSP egg had a total PBDE residue of 3ppb (Goodale 2008). Detection limits for PBDEs in this study may have been inadequate to detect low concentrations.

PCBs

Total PCBs (congener sum) in four of the earlier year's samples were below the detection level of 0.050 ppm; however, one LHSP egg had an extremely high total PCB concentration at 16.0 ppm wet weight. The highest total PCB concentration in the 2007 samples was 5.01 ppm wet weight ($\bar{x}$ = 1.33 ppm wet weight). Excluding the 16 ppm result, total PCB concentrations were greater in the 2007 samples. We cannot say that the difference is statistically significant due to the small sample sizes associated with our data sets. Henny et al. (1982) reported similar PCB concentrations in eggs of both species of storm-petrels collected from the Oregon coast in 1979. In that study, mean total PCBs from 11 LHSP eggs was 1.1 ppm wet weight (range of 0.87 – 1.6). In comparison to other seabird species from the same region of Alaska, glaucous-winged gull eggs collected from the Gulf of Alaska had a total PCB mean of 1.7 ppm wet weight with a range of 0.7 – 2.9 ppm wet weight (Vander Pol et al. 2009). Common murre eggs from St. Lazaria had a total PCB mean of 1.97 ppm wet weight (Vander Pol et al. 2004).

There are no laboratory toxicity benchmarks for storm-petrels, so the relevance of these results must be interpreted using surrogate species. Egg studies conducted using Aroclor 1254 and chickens have demonstrated reduced hatchability (17 percent) at 5 ppm, and embryonic mortality of 64percent at 10 ppm (reviewed in Hoffman et al. 1996). Comparative avian egg injection studies have shown that chickens are more sensitive to PCB 77 than turkeys, pheasants, mallards and goldeneye ducks, domestic geese, herring gulls and black-headed gulls. These results

suggest that the one egg at 16.0 ppm wet weight exceeded toxicological thresholds for PCBs established for other species. This concentration was greater than any other total PCB data reported from any storm-petrel or alcid eggs in Alaska (Ohlendorf et al. 1982), the Queen Charlotte Islands (Elliott and Noble 1993, Elliott et al. 1997), or Maine (Goodale et al. 2008). This same egg had much higher concentrations of other organochlorines (including DDT metabolites, dieldrin, mirex, HCB and various chlordanes). These elevated organochlorine results are internally consistent and suggest that at least some St. Lazaria storm-petrels are being exposed to very elevated PCB concentrations, and support the notion that adults are widely distributed in the non-breeding season and their contaminants exposure may vary due to undetermined factors (e.g., diet and/or geographic region).

Organochlorine Pesticides

Most organochlorines were not detected in appreciable quantities and a number of these contaminants, including some chlordane-related compounds, endrin, toxaphene, and lindane compounds were not present in eggs at the low detection levels of this study. The most toxic metabolite of DDT, p, p"-DDE, was found in concentrations below the effects threshold of 3 to 30 ppm wet weight (Blus 1995). Eggshell thinning would not be expected at the residue range we found. As we would expect due to geographic and temporal differences, and the reduced use of these pollutants in this hemisphere, the concentrations we found in 2007 (0.150 – 2.15 ppm wet wt, $\bar{x}$ = 0.508), were lower than those reported from 1979 egg samples of both LHSP and FTSP collected from the Oregon coast (Henny et al. 1982). In comparison, common murre eggs from St. Lazaria had mean p, p'-DDE residues of 2.44 ppm wet weight (Vander Pol et al. 2004).

Lindane (BHC) is an insecticide that readily volatilizes when applied to crops, allowing atmospheric transport and deposition by rain (EPA 2006). Lindane is minimally accumulated in avian tissues and undergoes a rapid metabolic breakdown (Blus et al. 1984), although residues were detected for 32 days in egg yolks after a dosing experiment (http://www.beyondpesticides.org/pesticides/factsheets/Lindane.pdf). Lindane and other HCH isomers tend to accumulate in colder climates, such as the Arctic, and concentrate in the food chain (EPA 2006). Residues were detected at very low concentrations in our study; they were well below levels where effects were noted.

HCB is a persistent fungicide which is also used in tire manufacturing and is an industrial waste product (Wiemeyer 1996). Our HCB residues were well below the threshold effects level of 35 ppm wet weight (Wiemeyer 1996). Initial HCB results were greater than residues reported in year 2007 eggs, also suggesting that exposure to this compound may be decreasing over time. No HCB was detected in lesser scaup eggs from two Alaska locations in 1999 (Fox et al. 2005). We found no information on avian toxicity threshold levels for this pesticide.

There are no literature-derived avian effects thresholds for mirex. Comparing our mirex data with other studies, LHSP eggs from the northwest Atlantic of Canada had mirex concentrations ranging from 0.010 to 0.043 ppm wet weight (Pearce et al. 1989). No other storm-petrel egg data were found, but mean murre egg mirex concentrations from the Gulf of Alaska increased

between 2000 and 2005 (Vander Pol et al. 2009). We cannot say that our 2007 lower mean egg mirex residues represent an actual decrease in exposure, although all use of this product in the United States was cancelled by EPA in December of 1977.

Concentrations of pentachlorobenzene in murre eggs from St. Lazaria were similar to our results (Roseneau et al. 2008). 1,2,4,5 – Tetrachlorobenzene was reported above detection levels in nine eggs. Residue values were between two to three times the detection limit. These trace residues are orders of magnitude below effects levels seen in rodent toxicological tests. Heptachlor epoxide concentrations were similar to those reported in common murre eggs from St. Lazaria Island collected in 2003 (Roseneau et al. 2008).

Mercury

Mercury, a strongly toxic heavy metal, is emitted primarily by fossil fuel burning (Pacyna and Pacyna 2002). Methylmercury is formed from inorganic mercury by the action of anaerobic organisms found in aquatic systems including marine systems. The methylation process converts inorganic mercury to methylmercury in the environment. Methylmercury and other alkyl mercury compounds are of concern because of their toxicities, and because they are commonly found in the environment. Bioaccumulation results in elevated concentrations in higher trophic levels, especially when lower trophic levels include fish.

In marine mammals, fish and seabirds, 90 - 100 percent of the total mercury in tissue is in the form of methylmercury (Fimreite et al. 1974, Wagemann et al. 1997; Burger and Gochfield 2004). This allows fairly direct comparisons between total mercury and methyl mercury values. Comparison with total mercury data from other seabird species eggs indicates that St. Lazaria storm-petrel eggs have comparable methyl mercury concentrations (Braune et al. 2001, Goodale 2008). Our results were very similar to LHSP eggs from two Maine studies that reported total mercury concentrations at 0.60 and 0.62 ppm wet weight (Goodale et al. 2009) and in ten eggs ranged from 0.29 – 1.25 ppm wet weight with a mean of 0.62 ppm (Goodale et al. 2008). Our observed concentrations however, were greater than residues from earlier investigations of storm-petrels in western Canada (Elliott and Noble 1993; Elliott et al. 1997).

Methylmercury results from St. Lazaria eggs exceeded avian toxicity thresholds for this contaminant. However, seabirds in general exhibit higher mercury concentrations than terrestrial birds because of the higher mercury burdens encountered in marine ecosystems (Thompson 1996).

While storm-petrel data from St. Lazaria are limited, there has been more extensive sampling of murre species at that location and at other sites in Alaska, as part of the Seabird Tissue Archival and Monitoring Project (STAMP). Direct comparisons cannot be made between these seabird species since they utilize different prey and have a different feeding strategy. Storm-petrels are surface feeders, whereas murres dive for food, and murres concentrate more on fish (e.g., sand lance and capelin) during the breeding period, while storm-petrels utilize a more diverse prey base that focuses largely on macrozooplankton. Given these ecological differences, these murre

data are still of interest since contaminant transport to remote locations such as St. Lazaria is thought to largely be via atmospheric transport and ocean currents. Thus these data may provide insight into contaminants deposition and accumulation at St. Lazaria relative to other parts of Alaska.

Elevated mercury concentrations were reported in murres at St. Lazaria and East Amatuli Island (both sites from the Gulf of Alaska), relative to sampling locations on Little Diomede Island and St. George Island in the Bering Sea (Christopher et al., 2002). With the exception of HCB and beta-HCH, contaminants concentrations reported in STAMP samples were significantly higher in common murre eggs collected at St. Lazaria compared to eggs from other colonies (Vander Pol et al. 2004). St. Lazaria murres had the highest concentrations of 4, 4'-DDE, total PCBs, and mirex, and the second highest dieldrin concentrations. Similar patterns were observed using principal components analysis, with the Gulf of Alaska samples appearing most distinct from the Bering Sea colonies, and with Bogoslof Island in the Aleutians intermediate from the other areas. Ohlendorf et al. (1982), also reported detectable organic pollutant residues were more frequent in seabird eggs from the Gulf of Alaska colonies than elsewhere in Alaska. DDE and PCBs were higher than average from this region in their study.

Other Metal Concentrations

Metal concentrations in sampled eggs were not at levels that have been associated with lowered reproduction or other detrimental effects on birds (Eisler 1985a, 1985b, 1987, 1988, 1998; Whitworth et al,1991; Heinz, 1979). Cadmium, lead, selenium, and mercury would be the metals of particular concern due to potential adverse effects. Burger et al. (2009), reported on metal residues in glaucous-winged gull eggs from the Aleutians. Our results for Cd and Pb (only one sample was greater than LOD) were lower than concentrations reported in that study. Our Se results (two samples greater than LOD) were similar to those results. We would expect lower metal concentrations in storm-petrels due to the difference in feeding strategies between the species.

Comparing Hg and MeHg results for St. Lazaria eggs did not show a clear relationship between the two analytes. MeHg ranged from 23 to 100 percent ($\bar{x}$ = 68 percent) of total mercury. Others have reported that greater than 90 percent of egg Hg levels are MeHg (Bond and Diamond 2009, Roseneau, pers. comm).

MANAGEMENT RECOMMENDATIONS

Based on the small numbers of samples collected to date, contaminants in storm-petrel eggs from St. Lazaria Island are at relatively low concentrations and do not represent a risk to this population. However**,** extrapolation from such a small sample size is difficult, particularly given

the high variability within some of the existing samples. Nevertheless, these results reflect input of contaminants to the Gulf of Alaska ecosystem through atmospheric and oceanic transport from distant sources and serve as initial baseline for this species in Southeast Alaska.. And although concentrations are primarily below toxic thresholds, our residues are greater for PCBs and some organochlorines than data reported in storm-petrel eggs in the past decade from the Queen Charlotte Islands of British Columbia (Elliott and Noble 1993; Elliott et al. 1997) and from Eastern Canada in 1984 (Pearce et al. 1989).

Future sampling of storm-petrels on St. Lazaria is recommended to examine long-term contaminant trends in these species, as pollution sources may change with time and the effects of climate change on contaminant exposure are unknown. Additional sampling of other storm-petrel colonies would be useful to determine if there is a geographical difference in contaminant loads. These data can be used to track contaminant trends in these species within the refuge. Spatial differences in colony contaminant concentrations may suggest different pollution sources and pathways of contaminant transport.

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APPENDIX A. Egg and Carcass Sample Weights

Appendix A. Storm-petrel egg (E) and carcass (C) weights, St. Lazaria Island, Alaska, samples from 2000 (00), and 2007 (07).

Sample ID	E00-1	E00-2	E00-3	E00-4	E00-5	E92-1	E07-01	E07-02	E07-03	E07-04	E07-05	E07-06	C07-07	E07-08	E07-09	E07-10	E07-11	E07-12	E07-13	C07-14
Weight (g)	15.4	7.8	8	8	8		7.2	7.1	8.5	4.6	7.1	4.4	6	5.9	9.4	8.1	6.8	7.4	8.3	17.3
Percent	32.6	21.4	24.1	13.2	26.6	8.17	19.4	11.8	18.7	13.8	13.5	13.2	16.1	18.6	__	13.8	12.6	14	12	24.3